On the Implementation of Hierarchy in the Ventral Visual Pathway

Stuart Geman

• Introduction

• Some experiments from Clay Reid’s lab

• Nonlinearity, functional connectivity, functional common input

• Invariance and functional common input

• Experiments of Polsky, Mel, & Schiller

• Experiments of Palanca and DeAngelis

• Computer experiments

• Topological representation
• Compositions of reusable parts (hierarchical representation)
  • Anatomical/physiological evidence
  • Compositionality – productivity and systematicity
  • Computation: fine-to-coarse representation yields coarse-to-fine computation

• Performance:
  • Curse of compositionality: backgrounds made of the same stuff
  • Blessing of compositionality: objects come equipped with their own background models

• The mystery of invariance in biological vision
  • Invariant representations are poor building blocks
  • Dilemma of invariance vs selectivity
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Some experiments from Clay Reid’s lab

up to 40% spikes <1ms synchrony
Some experiments from Clay Reid’s lab

Retention to LGN
Divergence
Synchrony

LGN → Cortex
Convergence
Synergy

Retina

V1 simple cell

<1ms correlation
\[\downarrow\]
~70% more effective in generating spike

Reid: special to retina-cortex connection
too many cortical-cortical synapses
(single events irrelevant)
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Nonlinearity, functional connectivity, functional common input

\[ f(x_1, \ldots, x_n) = f(\bar{x}) = \text{firing rate} \]

Anatomical connectivity to \( i \):
\[
    a_i = \left\{ \begin{array}{ll}
    \text{Constant if } f \text{ linear} \\
    \text{Function of } \bar{x} \text{ if } f \text{ nonlinear}
    \end{array} \right.
\]

Functional connectivity to \( i \):
\[
    FC = \frac{\partial f}{\partial x_i} (\bar{x})
\]

e.g. saturation

e.g. invariance (FC to target pattern!)

Conclusion:
\[ FC \neq AC \]
\[ FCI \neq ACI \]
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Invariance and functional common input

What circumstances promote Functional Common Input (FCI)?

Example:

- High ACI
- Low FCI

- Low ACI
- High FCI
Invariance and functional common input

More formally: consider generalization of “energy model” (Adelson & Bergen, Poggio & Riesenhuber, Amit & D. Geman)

\[ f(x_1, \ldots, x_n) = \sum_{\lambda=1}^{m} (\bar{a}^\lambda \cdot \vec{x})^p \]

\[ p \text{ large } \Rightarrow \]

- \[ f(x_1, \ldots, x_n) \approx (\bar{a}^* \lambda \cdot \vec{x})^p \quad \text{(where } \bar{a}^* \lambda \text{ achieves max)} \]

- \[ \frac{\partial f}{\partial x_i} f(x_1, \ldots, x_n) \approx p(\bar{a}^* \lambda \cdot \vec{x})^{p-1} a_i^* \]

= 0 away from maximizing filter
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Experiments of Polsky, Mel, & Schiller

Rat slice, layer 5 pyramidal cells

• Distance separation < 40 microns
• Time separation < 40 ms

Point: consistent with
\[ f(x_1, \ldots, x_n) = \sum_{p=1}^{m} (\bar{a}^x \cdot \bar{x})^p \]

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Experiments of Palanca and DeAngelis

Multi-unit recordings from MT of fixating macaque monkeys

“…may simply be a reflection of local cortical connectivity…”

“…synchrony has a limited role in feature grouping that is restricted to overlapping and/or collinear RFs.”
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Some experiments by Anastasia Anishchenko

HMAX Recognition Performance

Computer experiments
Computer experiments

(a) original image

(b) right-eye and left-eye templates

(c) filtered with right-eye template

(d) filtered with left-eye template
Computer experiments
Computer experiments

cell R activity: 0.62
cell L activity: 0.73
fci: 0.76

cell R activity: 0.59
cell L activity: 0.52
fci: 0.00

cell R activity: 0.39
cell L activity: 0.48
fci: 0.98

cell R activity: 0.59
cell L activity: 0.52
fci: 0.95

cell R activity: 0.71
cell L activity: 0.63
fci: 0.00

cell R activity: 0.68
cell L activity: 0.67
fci: 0.00

cell R activity: 0.63
cell L activity: 0.57
fci: 0.31

cell R activity: 0.64
cell L activity: 0.68
fci: 0.53

cell R activity: 0.58
cell L activity: 0.72
fci: 0.68
Computer experiments
Computer experiments (E. Bienenstock)

Integrate and fire model:

Each bar has 50 Poisson sources

\[
\begin{align*}
\left( \bar{a}^2 \cdot \bar{x} \right)^p & \quad \left( \bar{a}^3 \cdot \bar{x} \right)^p \\
\left( \bar{a}^1 \cdot \bar{x} \right)^p & \quad \left( \bar{a}^4 \cdot \bar{x} \right)^p \\
\end{align*}
\]

"complex cell"

\[
\sum_{\lambda \in \{1,2,3,4\}} \left( \bar{a}^\lambda \cdot \bar{x} \right)^p
\]
Build two of these and study *functional vs anatomical* input:

**Computer experiments**

![Graphs showing CCH (Cohort Cross-Correlation Histogram) for RF1 and RF2.](image)

- **RF1**
  - CCH with epoch = 10 sec
  - Firing rate neuron 1 = 63 Hz
  - Firing rate neuron 2 = 62.8 Hz

- **RF2**
  - CCH with epoch = 10 sec
  - Firing rate neuron 1 = 42 Hz
  - Firing rate neuron 2 = 41 Hz

**LINEAR (p=1)**
Computer experiments

Build two of these and study functional vs anatomical input:

![Graph showing CCH with p = 10 and bin = 1 ms.]

- Firing rate neuron 1 = 55.8 Hz
- Firing rate neuron 2 = 56.4 Hz

![Graph showing CCH with p = 10 and bin = 1 ms.]

- Firing rate neuron 1 = 62.7 Hz
- Firing rate neuron 2 = 62.1 Hz
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• Topological representation
• temporary topological structure (von der Malsburg)
• divergence/convergence bottom-up and top-down (Abeles, Grossberg, Mumford, Ullman…)
• local & partial synchronies
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